Characterization of nonlinear nonreciprocal propagation in semiconductor amplifying waveguide optical isolators

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[INTRODUCTION] Semiconductor waveguide optical isolators based on nonreciprocal loss are composed of an SOA covered with a ferromagnetic metal. They have the advantage of monolithic integration with semiconductor lasers compared to conventional free space optical isolators. So far, demonstrations of nonreciprocal propagation have been reported for TE and TM mode operation [1,2]. Since optical gain of the SOA compensates the propagation loss from the ferromagnetic metal in these waveguide optical isolators, it is important to characterize the amplifying waveguide optical isolators as SOA as such for full understanding of their performance. One of the important issues is gain saturation of the amplifier. Here we report on the nonlinear nonreciprocal propagation characteristics in TM mode 1285nm transparent semiconductor amplifying waveguide optical isolators. **[CHARACTERIZATION]** We measured saturation effects in InGaAlAs MQW TM mode semiconductor waveguide optical isolators with $Co_{50}Fe_{50}$ as the ferromagnetic metal [2]. The device is 2mm-long, AR-coated, and has gain peak at $\lambda = 1285$nm. The device becomes transparent for forward propagating light at a bias current of 200mA, and shows 7.5dB isolation for 0dBm input light from an external cavity tunable laser. In this work, we fixed the input wavelength at 1285nm and the bias current at 200mA. We changed the input light intensity between -10dBm and 10dBm, and characterized the optical gain and isolation. **[MEASUREMENT RESULTS]** Fig. 1 shows the measurement result. The fiber to chip coupling loss equals 10dB per facet. We calibrated the optical power of the output light intensity. With increasing the input light intensity, the device shows saturation at -5dBm for the backward and -2dBm for the forward propagating light. As a result, the isolation increases with increasing the input light intensity. **[DISCUSSION]** The measurement result of Fig. 1 shows that the amplifying waveguide optical isolator has higher propagation loss for larger backward optical intensity. In general, ferromagnetic metals such as $Co_{50}Fe_{50}$ have a large carrier density, hence do not show saturation absorption below 10dBm input light. Therefore, the observed nonlinear nonreciprocal propagation effect results from gain saturation of the InGaAlAs MQW amplifying layers. In conclusion, in amplifying waveguide optical isolator it is necessary to consider saturation effects for forward and backward propagating light.

[1] H. Shimizu et al., J. Lightwave Tech. **24**, 38, (2006). [2] W. Van Parys et al., Appl. Phys. Lett., **88**, 071115, (2006).

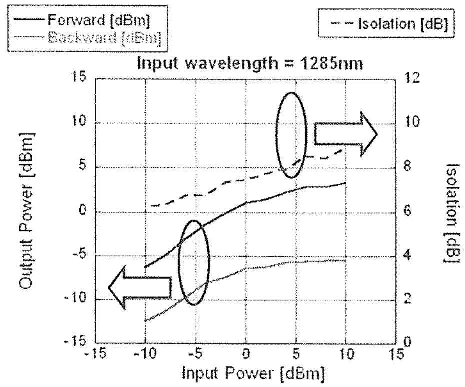

Fig. 1 Nonlinear nonreciprocal propagation measurement results. The input light is 1285nm TM mode. The measurement temperature is 20deg. A 1kG magnetic field was applied by a permanent magnet.

半導体能動導波路光アイソレータの非線形な非相反伝搬特性の評価

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[はじめに] 非相反損失に基づく半導体導波路光アイソレータは半導体光増幅器と強磁性金属の組み合わせからなり、端面出射型半導体レーザとモノリシック集積化が可能という特長を有する。これまで、TE, TM モードの双方に対して非相反伝搬の実証が報告されている[1,2]。上述の導波路光アイソレータでは半導体光増幅器の利得によって強磁性金属がもたらす伝搬損失を補償しており、半導体光増幅器としての評価も重要である。これまで上記用途の半導体光増幅器は低動作電流・短素子長・高増幅度といった方針のもとに作製され、飽和特性については必ずしも考慮されていなかったが、飽和特性も重要な評価項目の一つである。そこで我々は無損失化が達成されている波長 1285nm の半導体導波路光アイソレータの非線形な非相反伝搬特性を評価したので報告する。**[測定方法]** 評価した半導体導波路光アイソレータは InGaAlAs 量子井戸活性層 TM モード半導体光増幅器と $Fe_{50}Co_{50}$ 合金強磁性金属からなる[2]。素子長は 2mm、利得ピーク波長は 1285nm であり、200mA のバイアス電流によって前進波に対する挿入損失がゼロ、強度 0dBm の入力光に対して 7.5dB の光アイソレーションを示す。本研究では外部共振器型波長可変レーザからの入力光波長を 1285nm、バイアス電流を 200mA に固定し、強度を-10dBm から 10dBm まで変化させ、前進波・後退波の光増幅、光アイソレーションを評価した。**[測定結果]** 測定結果を図 1 に示す。光ファイバ/素子間の結合損失は 10dB であるが、出力光に対しては補正済みである。入力光強度の増大に対し、後退波に対しては約-5dBm、前進波に対しては約-2dBm から増幅度が飽和をはじめる。結果として前進波の出力光強度から後退波の出力光強度を引いた光アイソレーションは、入力光強度が増すにしたがって増大することが明らかになった。**[考察]** 前進波と後退波を同時に入射させた実験結果ではないことを念頭に置く必要があるが、図 1 の測定結果は戻り光の強度が増すほど相対的に強く $Fe_{50}Co_{50}$ に吸収され、光アイソレーションが大きくなることを表している。本研究で用いている強磁性金属 $Fe_{50}Co_{50}$ はキャリア密度が高い金属であり、10dBm 程度の光強度では吸収特性や磁気光学効果が飽和することはないと考えてよい。したがって非線形な非相反伝搬特性は InGaAlAs MQW 活性層の飽和特性を反映した非相反伝搬特性であり、前進波・後退波に対する飽和特性まで考慮した素子設計が必要であることを示している。

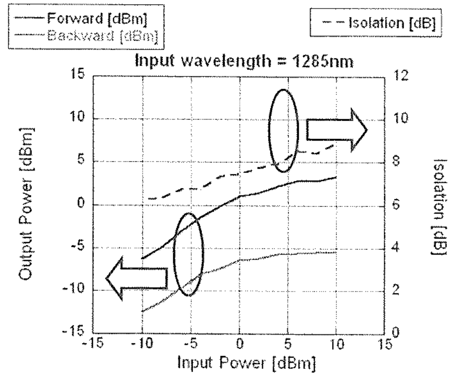

図 1　非線形な非相反伝搬特性の測定結果。入力光は波長 1285nm の TM モード、測定温度は 20 度、バイアス電流は 200mA。永久磁石により 1kG の磁場を印加し、前進波、後退波の伝搬特性を評価した。素子は長さ 2mm、AR coated。

[1] H. Shimizu et al., J. Lightwave Tech. **24**, 38, (2006). [2] W. Van. Parys et al., Appl. Phys. Lett., **88**, 071115, (2006).

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